

ADRPM-VII APPLIED TO THE LONG-RANGE ACOUSTIC DETECTION PROBLEM
Edward Shalis, Gerald Koenig
Countermeasures Branch
Tank-Automotive Command
Warren, Mi 48090

INTRODUCTION

An acoustic detection range prediction model (ADRPM-VII) has been written for IBM PC/AT machines running on the MS-DOS operating system. The software allows the user to predict detection distances of ground combat vehicles and their associated targets when they are involved in quasi-military settings. The program can also calculate individual attenuation losses due to spherical spreading, atmospheric absorption, ground reflection and atmospheric refraction due to temperature and wind gradients while varying parameters effecting the source-receiver problem. The purpose of this paper is to examine the strengths and limitations of ADRPM-VII by modeling the losses due to atmospheric refraction and ground absorption, commonly known as excess attenuation, when applied to the long range detection problem for distances greater than 3 kilometers.

BASIC ASSUMPTIONS OF ADRPM-VII

The basic assumptions of ADRPM-VII are the following:

- o ADRPM is based on simplified atmospheric conditions adjusted to a standard day during the seasonal year. In the real world, a standard day does not exist since temporal variations must be allowed for in all environmental propagation measurements. The effect of these variations can only be measured with sound speed profile soundings.

- o The noise emitted by the source is omnidirectional, broadband and continuous.

- o The primary propagation path is near the surface of the ground.

- o All attenuation elements are considered independent of each other with the total attenuation arrived from the summation of its individual parts.

- o The ground is defined as a rigid plane or a plane of finite impedance and the model uses a table of values of ground cover loss that is linearly dependent on the distance from the source.

- o "The model is developed in the context of a need to estimate noise levels of surface vehicles at distances ranging from tens of meters to hundreds of meters for a relatively wide range of environmental conditions" according to Fidell and Bishop (ref. 1).

ATTENUATION DUE TO REFRACTING ATMOSPHERES

The model calculates propagation loss in a refractive atmosphere by applying a correction term to the reflected and surface wave terms derived from non-refracting atmospheres. This correction term, which is based on ray tracing, considers the existence of shadow zones for upward refraction and an intensity ratio modification for the downward refracting case (ref. 2).

Several representative atmospheres have been chosen from the given meteorological profiles in ADRPM for analysis of the models refractive effects. Average wind velocities $u(r)$, surface roughness parameter $z(o)$, and Monin stability length L are given for each selected profile:

Neutral Profiles: Vertical temperature lapse of $\sim .01$ degrees Kelvin per meter and turbulence due to wind only. The following latitude and season was chosen for analysis:

1. Mid-latitude (45°N), summer, with

$$\begin{aligned}u(r) &= 3.3 \text{ mph,} \\z(o) &= 0.15 \\ \text{surface temperature} &= 73.8^{\circ}\text{F.}\end{aligned}$$

Stable Profiles: A positive temperature gradient and damped turbulence due to thermal inversion only.

1. Mid-latitude (45°N), summer night, with

$$\begin{aligned}u(r) &= 2.5 \text{ mph} \\z(o) &= 0.15 \\L &= 39.65 \\ \text{surface temperature} &= 62^{\circ}\text{F} \\ \text{temperature gradient} &= .02 && \text{for 0-40 meters} \\ &= .01 && \text{above 40 meters}\end{aligned}$$

2. Midlatitude (45°N), winter night, with

$$\begin{aligned}u(r) &= 4.4 \text{ mph} \\z(o) &= 0.15 \\L &= 38.6 \\ \text{surface temperature} &= 21^{\circ}\text{F} \\ \text{temperature gradient} &= 0.07 && \text{for 0-40 meters} \\ &= 0.02 && \text{above 40 meters}\end{aligned}$$

Unstable Profiles:

1. Midlatitude (45°N), summer daytime, with

$$\begin{aligned}u(r) &= 3.6 \text{ mph} \\z(o) &= 0.15 \\L &= \sim 16.88 \\ \text{surface temperature} &= 84^{\circ}\text{F} \\ \text{temperature gradient} &= \sim .05 && \text{for 0-65 meters} \\ &= \sim .02 && \text{65-165 meters} \\ &= \sim .01 && \text{above 165 meters}\end{aligned}$$

2. Midlatitude (45°N), winter daytime, with

$$u(r) = 6.5 \text{ mph}$$

$$z(o) = 0.15$$

$$L = -243.5$$

$$\text{surface temperature} = 36^{\circ}\text{F}$$

$$\text{temperature gradient} = -.02$$

$$= -.01$$

$$= -.004$$

for 0-15 meters

15-25 meters

above 25 meters

A: Attenuation Due To Upward Refraction

The upwardly bending sound energy algorithms have evolved through the efforts of several investigators, with Felt (ref. 3) making the greatest contribution. Felt's ray tracing procedure requires a numerical solution to a differential equation to determine the ray path as a function of the initial angle of propagation. For a specified source height $h(s)$ and receiver height $h(r)$, attenuation is based on the distance to the shadow zone $d(s)$, which is defined by:

$$d(s) = (h(s)/k)^{1/a} + (h(r)/k)^{1/a} \quad (1)$$

where: $h(s)$ = source height
 $h(r)$ = receiver height
 $d(s)$ = distance to the shadow zone

and a, k are parameters that are determined from Snell's law of refraction for various meteorological profiles.

The attenuation due to upward refraction is capped by a maximum frequency dependent value that is dependent on the distance to the shadow zone, as determined from equation 1. The value of attenuation $A(e)$ is calculated from:

$$A(e) = A(\text{max})(1 - d(s)/d) \quad (2)$$

For a source to distance receiver d , the model considers two cases:

$d < d(s)$ where the receiver is not in the shadow zone
 $d > d(s)$ where the receiver is in the shadow zone

B: Attenuation Due To Downward Refraction

For the downwardly refracting case, a fitting function based on the initial propagation angle α and the distance from the source to where the ray strikes the ground x is given by (ref. 4):

$$\tan \alpha = Mx^b \quad (3)$$

where M, b are determined in much the same way as a, k were determined for the upwardly refracting case in equation 1.

ATTENUATION DUE TO GROUND IMPEDANCE

The attenuation due to the effect of a sound wave interacting with a surface of finite impedance is based on the work by Embleton, Piercy, Olson (ref. 5) and Delany, Bazley (ref. 6). ADRPM-VII calculates the effect of ground impedance based entirely on the coherence of incoming waves. However, the stable conditions assumed for the phase dependent calculations are unlikely to exist for longer ranges since the effect of inhomogeneity on the delicate phase relationships is ignored.

Nevertheless, the theory predicts losses of 50-70 dB for some conditions. Since losses beyond 30 dB are rarely observed, the model handles this empirical discrepancy by decreasing the effects of ground impedance for distances greater than 500 meters.

In addition, the model accounts for a non-uniform surface by requiring a single user supplied parameter. This parameter, h , is the root mean square surface roughness height. Based on reference 6, h yields a smoothness, s , that represents the fraction of the reflected energy that is specularly reflected.

However, the unique topography along the propagation path is not included in the model. This is an important omission since sloping ground can control the phase as well as serve as a barrier by intercepting incoming rays.

RESULTS AND DISCUSSION

Field data of stationary and moving helicopters have been analyzed over ranges from 300 meters to 12 km. The results show a built-in variability of the continuously received signal for ranges between 2 and 5 km. At these source-receiver distances, the refractive atmospheric state, with all its existing temperature and changing wind directions, will have a variable attenuation effect on the propagating rays and consequently produce a variable received signal.

In the field, it remains difficult to determine the unique local sound speed profile for all threat directions, especially since the sound speed profile can change with the next gust of wind or the next reversal of wind direction. This problem of measuring time varying speed profiles occurs at all field locations that we have visited across the United States. However, the meteorological conditions are still determined only at the detector during ground vehicle testing.

The area of the atmosphere that primarily effects ground vehicle vulnerability for the medium detection distances is in constant change due to its turbulence. A wave propagating through this boundary layer is variable in amplitude and is influenced by the daily cycle of stable and unstable meteorological conditions that repeat themselves several times each day. TACOM data shows that noon time provides the largest variation of amplitude, sometimes as much as 7 to 8 dB. The fluctuations are less and also slower during the morning and early part of the evening. In all cases, it is best to obtain sound speed profiles each time that a set of data is

measured, with as many locations as possible, but at least two extreme readings that would cover the source and the projected receiver distance.

For ranges beyond 5 km, field data signals are intermittent, where there may be no signal received for long segments of the propagation path. This behavior is expected, since randomness of atmospheric gradients and changing terrain features are common. The potential of several inversion layers existing is always there when the propagation path is great.

In addition, for distances greater than 5 km, the received signal is fairly constant in level and the sound pressure does not follow the classical spherical divergence law. This variation from spherical spreading may be produced by the large number of multiple ray paths that are possible, with multiple ray arrival producing a mixture of phase that tends to produce a fixed sound pressure level.

Since every sound propagation study in the long range is unique, the model was used to calculate the effect of changing a single parameter on the received signal. For instance, the source receiver geometry and the atmospheric refraction conditions were varied by selecting user parameters available from the program. The results of excess attenuation calculations were then compared for different standard days/nights.

Figure 1 represents the total sound pressure level for the isothermal-no wind condition for short detection distances of 200 meters. This case illustrates the removal of refraction as an attenuation effect since the rays will travel in a straight line, with time of travel between equally spaced distances remaining the same. For low frequencies, especially 20 and 80 Hz, atmospheric absorption can be ignored and the curves illustrate the effect of spherical spreading and ground effects.

The effects due to spherical spreading and atmospheric absorption were removed so that losses due to refraction and ground impedance could be examined more closely. Figure 2 examines the effect of isothermal atmospheres, where the excess attenuation is due to ground effects. Figure 2 shows that the model calculates the ground effect as a linear function of distance.

Both atmospheric and wind refractive effects were investigated for the mid-latitude summer neutral profile for both the downwind and upwind cases, as seen in Figures 3 and 4. The excess attenuation is capped at 1 km and remains fixed for the entire range beyond 1 km. For the upwind case, the cap starts at 2 km and the values remain fixed throughout the remaining ranges. One point should be made at this time; the values of excess attenuation for both cases are too low and refractive effects appear to be missing from 2 km onwards.

The change in the meteorological profile to mid-latitude summer night is shown in Figures 5 and 6 for both wind directions. Again, the values are capped and the excess attenuation due to refraction is too low in value.

Consequently, there is a maximum distance beyond which the model should not be used. This distance is normally 1 km but can be extended to 2 km for atmospheric conditions that are unusually uniform. After 2 km, a model that uses instantaneous atmospheric readings to determine the velocity of sound profile should be used to calculate propagation losses. This latter model should use statistics determined by the defined topography and atmosphere to discuss variations in the received signal amplitude.

CONCLUSION

ADRP-VII solves the detection problem even though detailed knowledge of temperature, humidity, variation in terrain features and wind gradients are not available to the user. Given these conditions, the model can give misleading information when compared to a model that performs ray tracing refraction based on accumulated local meteorological information.

Perhaps a two model approach is required to solve the long range detection problem. ADRPM can be used for ranges below two kilometers where general meteorological conditions are approximated by readings at no more than two locations and terrain features are determined visually. Beyond two kilometers, a more elaborate model that is based on detailed atmospheric information would take over and perform the analysis.

REFERENCES

1. Fidell, S., Bishop, D., "Prediction of Acoustic Detectability", TACOM Technical Report No. 11949, p.9 (1974).
2. Francis, W.P., "An Analysis of the TARADCOM Acoustic Detection Range Prediction Model", TACOM Technical Report No. 12467, pp.39-53 (1979).
3. Felt, J., "Modified Acoustic Range Prediction Model (ADRP-V)", TACOM Technical Report No. 12544 (1980).
4. Felt, J., Ibid, p.10
5. Embleton, T., Piercy, F. and Olson, N., "Sound Propagation Over Ground of Finite Impedance", J. Acoust. Soc. Am., Vol. 59, pp.267-277 (1976)
6. Delany, M., and Bazley, E., "Monopole Radiation in the Presence of an Absorbing Plane", J. Sound Vib., Vol. 13, pp.269-279 (1970)

ADRPB Barrier Effects on Sound Pressure Level vs Distance (Isothermal-Calm)

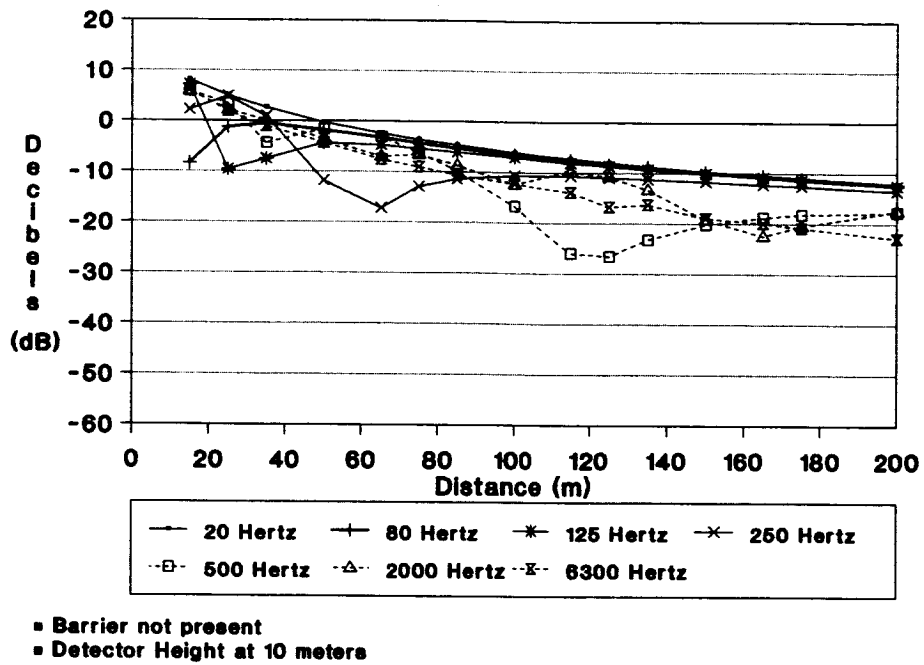


FIGURE 1

ADRPB Excess Attenuation vs. Distance For Isothermal Profile (Target at ht=3m, Detector at ht=50m)

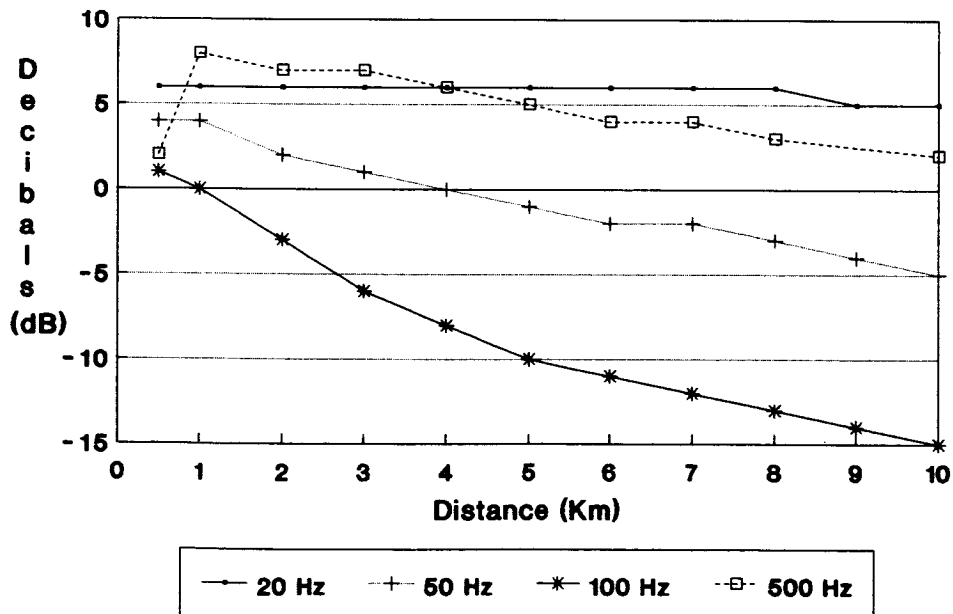


FIGURE 2

ADRPMP Excess Attenuation vs. Distance
For Downwind, Mid-Latitude Summer Neutral Profile
(Target at ht=3m, Detector at ht=50m)

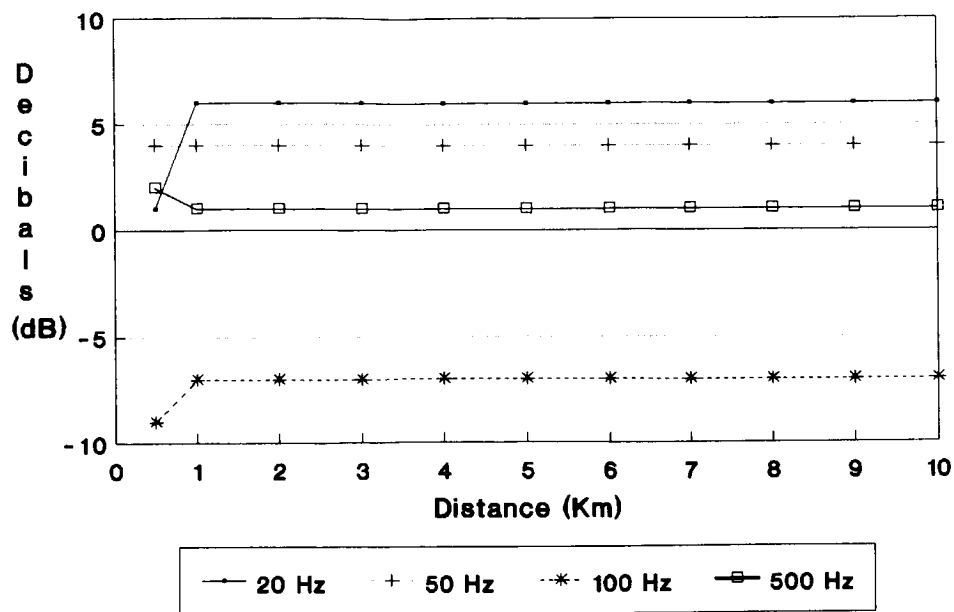


FIGURE 3

ADRPMP Excess Attenuation vs. Distance
Upwind, Mid-Latitude Summer Neutral Profile
(Target at ht=3m, Detector at ht=50m)

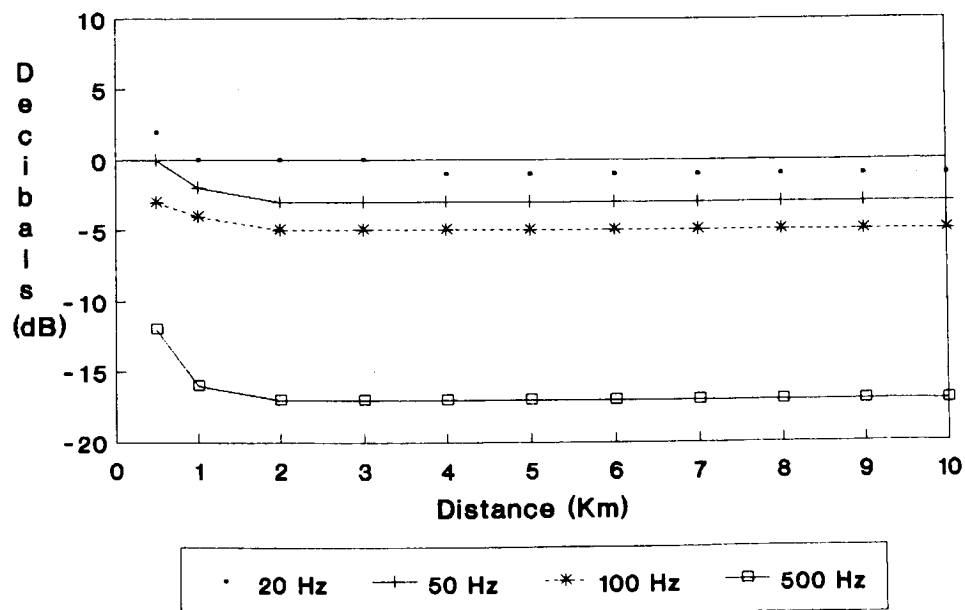


FIGURE 4

ADPMP Excess Attenuation vs. Distance
For Downwind, Mid-Latitude Summer Night Stable Profile
(Target at ht=3m, Detector at ht=50m)

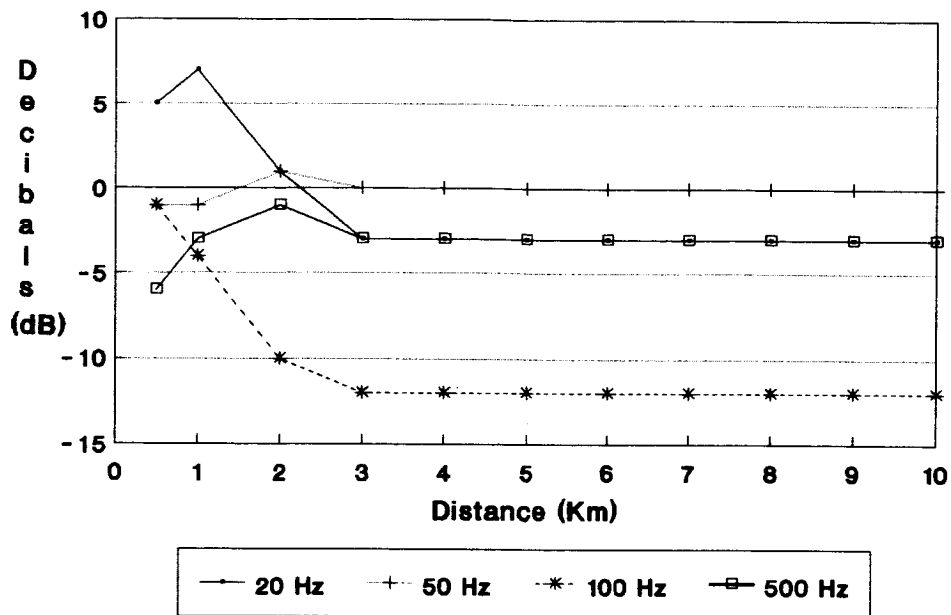


FIGURE 5

ADPMP Excess Attenuation vs. Distance
For Upwind, Mid-Latitude Summer Night Stable Profile
(Target at ht=3m, Detector at ht=50m)

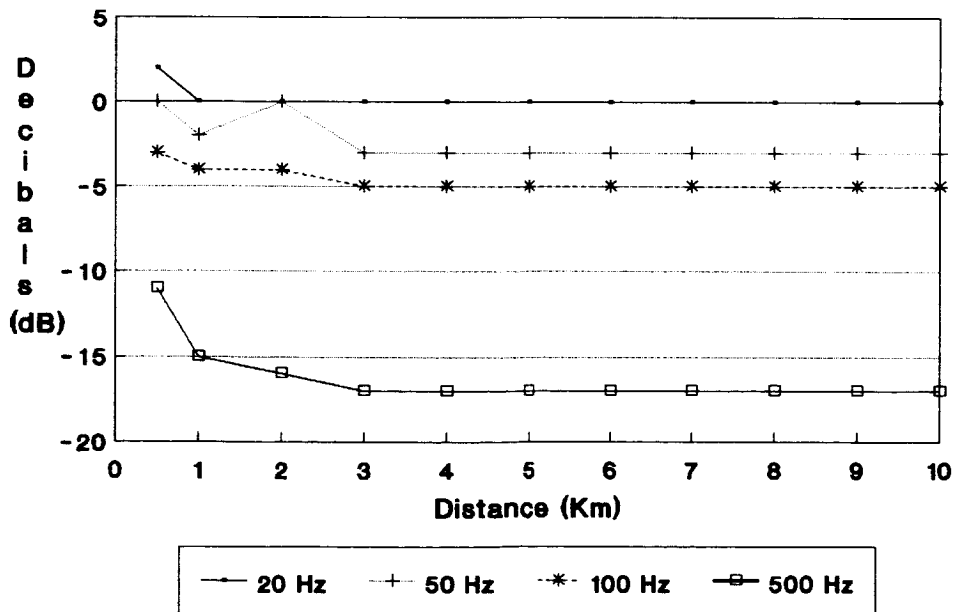


FIGURE 6